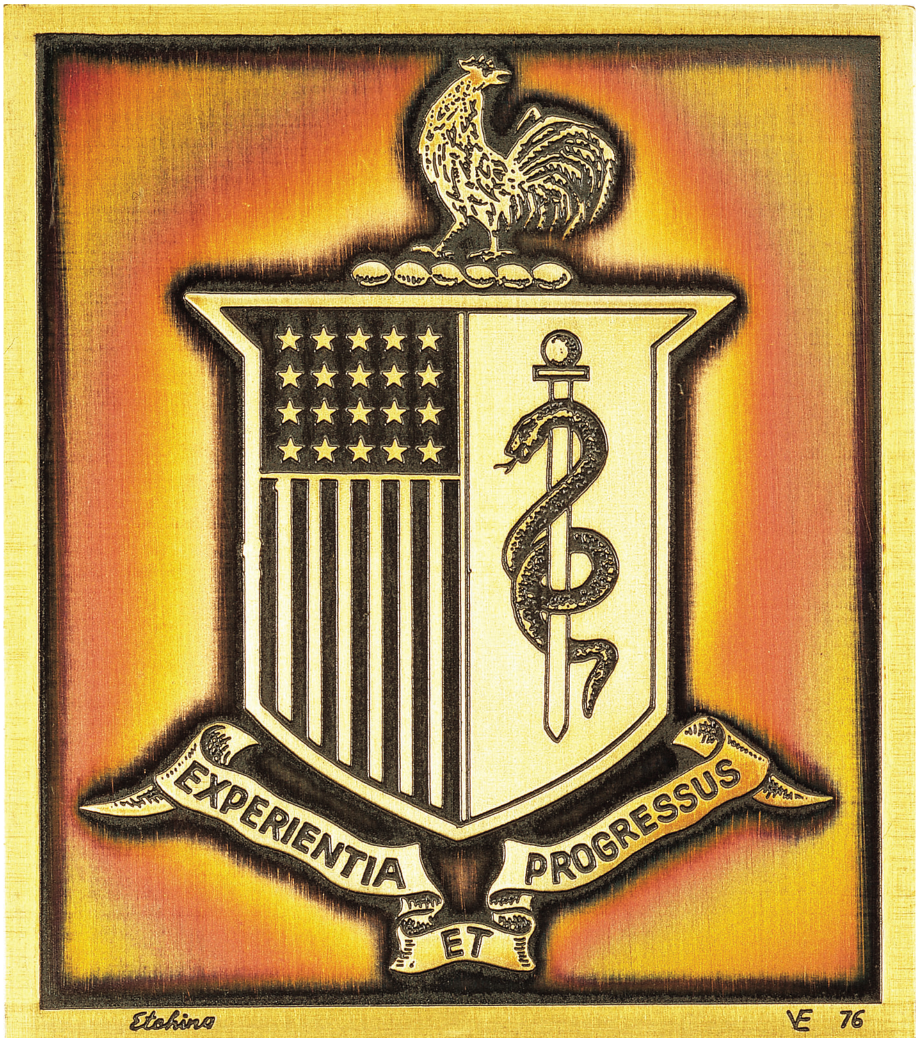
MILITARY QUANTITATIVE PHYSIOLOGY: PROBLEMS AND CONCEPTS IN MILITARY OPERATIONAL MEDICINE



The Coat of Arms
1818
Medical Department of the Army

A 1976 etching by Vassil Ekimov of an
original color print that appeared in
The Military Surgeon, Vol XLI, No 2, 1917

The history of the research scientist in what is now the Army Medical Service Corps extends from its beginnings in the Sanitary Corps at the beginning of World War I, to a dramatic surge of activity and scientific advances during World War II, to a handful of dedicated uniformed researchers who continue to lead science for the soldier today. Their work has contributed to the scientific foundation of modern medicine. Army physiology, along with its civilian counterpart, came into full bloom in the 20th century, aided by the rapid development in chemistry and physics, and in other areas of medicine, technology, and economic growth. In the 21st century, the convergence of information and computer sciences with biomedicine is promoting a new breed of scientists who will apply their basic understanding of human physiology to advance comprehensive and predictive models that will reduce injuries, improve and sustain performance, and, ultimately, improve a soldier's success on the battlefield. The military scientist has a unique capacity to simultaneously excel on the national scientific stage and to translate and interpret findings that benefit soldiers and civilians alike. In addition, uniformed scientists have and will continue to deploy to combat operations in support of our nation's wars. From these operational experiences, military scientists gain important perspectives that shape their relevant research.

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Predictive models to help lighten the soldier load, improve load distribution, tailor appropriate physical training, select the right equipment, and choose appropriate biomechanical techniques will all facilitate soldier load carriage performance. These tools will allow service members to conduct missions more effectively at lower energy costs and with fewer injuries.

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MILITARY QUANTITATIVE PHYSIOLOGY: PROBLEMS AND CONCEPTS IN MILITARY OPERATIONAL MEDICINE

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Foreword

Few human activities demand or deserve as much attention of the citizens of a nation as the array of man-made and natural "environmental" threats faced by the soldiers and other warriors defending that nation—those that pose the risk of disease, injury, combat wounds, and even death. Scientists charged with understanding these threats and mitigating the potential effects must use the most advanced techniques and sophisticated analysis possible in this endeavor. This book is the Army's first detailing research in computational physiology models and highlighting pivotal research. It outlines the extent to which basic and applied biomedical scientists, clinicians, modelers, and others strive to understand the extent of these threats, and provide intellectual and materiel options to mitigate these risks.

Quantification of this information is critical, as medical standards aimed at protecting soldiers must represent the best available science. Development of protective equipment requires data-driven support of new approaches that clearly demonstrate effectiveness while addressing affordability and cost. Virtual prototyping has led to valid and useful models of human tolerances focused on ensuring that our service members are provided with modern warfighting systems that safely and effectively contribute to mission accomplishment. Without compelling data, efforts at providing America's warriors with the best materiel and doctrinal solutions to the adverse conditions under which they must operate—and protections against harm that might result—are severely limited and potentially restrict the full range of soldier technological capabilities.

Throughout history, work of this nature has extended well beyond military applications alone; it reaches outside of the military environment because of its dual-use nature. Thermal strain, load carriage, hydration guidelines, performance nutrition, fatigue, and physical training injury prevention are all topics in which the military is recognized as having unique expertise. Countermeasures to more specific military hazards, such as blast and laser injuries, have contributed to the civilian community in establishing protective criteria in a wide array of applications, such as airbag inflation rates and international protection standards for commercial lasers. The efforts described in this text represent the government's largest intramural performance physiology research program and include important academic and industry collaborations. Cutting-edge modeling—applying mathematics and physics to understand important life science problems related to training, eating, resting and protection—has resulted in enhanced systems to augment decision-making in new and complex situations.

The lengthy institutional investment in these investigations by the US military has led to iterative, ongoing contributions by the leaders in each field of endeavor. Simulations and models also incorporate metaanalysis of previous studies, thus including lessons learned from years of research and providing increasingly more vigorous evaluations with each new dataset. For example, the US Army Research Institute of Environmental Medicine (USARIEM) hydration tables are used worldwide, preventing heat injuries caused by inadequate water intake. Future refinements with personalized monitors that signal individual water needs, perhaps through a wearable system, will provide further protection of health and optimize performance.

It is with great pride that Army Medicine serves as the focus for compiling and formally disseminating these critical insights. This is a significant book, not only for the technical information that it contains, but also as documentation of the collective works of numerous dedicated Army scientists—all committed to the protection of the nation's defenders and the global human family.

Lieutenant General Eric B. Schoomaker, MD, PhD
The Surgeon General and Commanding General
United States Army Medical Command

Washington, DC
December 2011

Preface

Where is the Life we have lost in living?

Where is the wisdom we have lost in knowledge?

Where is the knowledge we have lost in information?

— T. S. Eliot, *The Rock*, 1934

This book summarizes major Army research efforts to quantify and model militarily relevant physiology. These chapters highlight the translation of this research into useful predictive tools. The tools are of importance to medical planners, materiel developers, commanders, and, in many cases, every soldier. These chapters detail the experimental basis for many of the predictive tools that are currently in use. This book is written for military clinicians and medical researchers who may be reasonably expected to explain some of this background, as well as those who will extend the research. The sophisticated research and models should be opaque to most of the ultimate users, with models and algorithms derived from this research built into larger Army models and systems, and used to make better equipment and provide better guidelines for hazard management.

Nevertheless, many people will find this book interesting because it details research on topics that affect everyone in everyday life, including how we sleep, eat, and exercise, as well as more specific topics such as the effects of caffeine on performance, risks associated with laser pointers, and even Army blast models that have influenced safety thresholds for car airbag deployments. Every person should be interested in these areas of medical research!

The military physiology problem set has not changed greatly since the Revolutionary War and should continue to guide an ever-accelerating effort to combine models for high priority predictions pertinent to fatigue, physical performance, cognitive performance, injury risk, and human limits in the face of militarily relevant stressors and threats. What is new in this century is the explosive advance of computing technology and neurobiology. This provides new understanding of how to make knowledge more useful and available to soldiers who expect to be able to obtain this knowledge through their personal mobile devices or as an automatic readout of choices from other electronic monitors and systems.

Military medicine is now racing to catch up with these rapid advances and new expectations in science and technology. This cultural shift with the transition from discovery science to information science should be apparent in these chapters. This revolution in medical research has also been called "convergence science," characterized by the increased reliance on mathematics, physics, and computer engineering to solve problems in the life sciences. The Army began committed support to the development of medical decision support tools in the past decade, led by Jaques Reifman and his team in the Bioinformatics Center at the US Army Medical Research and Materiel Command. The Department of Defense (DoD) has now initiated funding for a new core program (starting in 2010) that includes support to computational biology modeling efforts.

The first year of this effort expands on the topic of one of the chapters in this book (Chapter 11, Load Carriage in Military Operations: A Review of Historical, Physiological, Biomechanical, and Medical Aspects) with the concerted development of a comprehensive model of load carriage led by the US Army Research Institute of Environmental Medicine (USARIEM). Future advances in applied physiology require this problem-solving convergence approach, as well as new appreciation for data sharing, cloud computing, more comprehensive supermodels, and an integrating focus on the neurobiology of the warfighter.

The Army's real-world problems and interesting test environments are the unique strength of military physiology research, where investigators can lead academic collaborators in valuable field studies with soldiers pushing to the limits of human performance. These conditions are not only often messy for purposes of scientific design, but also possibly unattainable in a laboratory setting. Four examples (chapters 5, 6, 10, and 11) highlight the fascinating and unique research captured in this book.

Bruce Stuck (Chapter 5, In Vivo Diagnostics and Metrics in the Assessment of Laser-Induced Retinal Injury) is a national resource. As the single central repository of more than 40 years of research on health and performance consequences of laser eye exposure, he has charted constantly evolving laser hazards that affect eye safety and protection for our troops, as well as consequences to performance in aviation and other militarily relevant scenarios. This research has been foundational in national standards for laser safety and contributed to current international treaties on blinding lasers.

Colonel (Ret) Wayne Askew (Chapter 6, Nutrition and Military Performance) is a pioneer who was able to break funding silos by sharing precious nutrition research dollars to investigate hydration in environmental extremes—a natural companion topic to Army nutrition problems—and establishing transdisciplinary studies of Ranger students involving energy metabolism extremes and performance outcomes. The results of these studies addressed real soldier problems, but at the same time also advanced basic science in human osmoregulation and energy metabolism.

Jim Stuhmiller (Chapter 10, Blast Injury: Translating Research Into Operational Medicine) is an early pioneer in today's convergence science who has been dedicated to pulling together data and tools into more comprehensive predictive models that address real soldier protection standards. Thirty years ago, he recognized the need for the DoD to model the combined biophysical stressors related to military equipment, along with environmental, metabolic, and other factors that influence model validity. It is unlikely that the DoD would have a valid blast overpressure model and method for health hazard assessments today without his vision and the dedication of his team. Without these models, there would be ongoing safety concerns about an entire generation of effective high-powered weapons systems that were instead permitted to be fielded on the basis of better scientifically based standards derived from the predictive models.

Major (Ret) Joe Knapik (Chapter 11, Load Carriage in Military Operations: A Review of Historical, Physiological, Biomechanical, and Medical Aspects) represents one of the finest examples of our dedicated military physiologists who lived and breathed practical solutions to military physiology problems. His chapter on load carriage reflects one of his areas of interest and an entire career of laboratory and field experiments, personal experience, and comprehensive scope of the field. His efforts have spanned the medical and human systems communities to advance the development of load carriage systems while conducting studies with the preventive medicine community to reduce physical injuries. His pioneering efforts provide the foundation for a new major load carriage modeling initiative that will produce a sophisticated virtual prototyping capability to materiel developers.

This book started long ago as a third volume in the *Textbooks of Military Medicine* environmental extremes series, but was restructured to address the modern requirements for quantitative models and predictive tools. This book should help mark the culmination of an earlier era of research, summarizing the important accomplishments and providing the platform to launch to the next level. Future work should take full advantage of the biomedical research captured in these chapters, in combination with new capabilities in information science and cyber infrastructure, to take an integrative approach to solving real-world problems for soldiers.

For example, laboratory sleep studies have uncovered basic principles for sleep and performance, but soldiers sleep in the heat in Southwest Asia and in a hypoxic environment at altitude in some parts of Afghanistan; these environmental factors can have dramatic effects on the quality of restorative sleep. Sleep is affected by other ambient operational conditions such as noise and light, as well as overlapping psychological concerns or the amount of caffeinated energy drinks consumed earlier in the day. Heat and altitude affect appetite and energy consumption for soldiers, with secondary effects on water consumption. The skin is a critical protective barrier and regulator for our internal physiology, responding to external challenges (eg, temperature and psychological stress) and threats (eg, ultraviolet radiation) and having regulatory functions (eg, sweating and skin blood flow responses). These dermal influences are all interactive with other factors covered in this book, ranging from antioxidant nutrition to body size and adiposity to hydration status. These complicated interactions have not yet been captured in any single model. This places a demand on the reader, because the chapters represent discontinuous efforts, including independent modeling efforts in various states of maturity.

Readers are challenged to use some imagination going from chapter to chapter to mentally bridge the artificial divisions established around disciplines and problem sets, and to think about how we move away from this balkanization to address an integrated soldier health and performance model, just as military medicine needs to move to an overall strategy of integrative health. Advances in neurobiology will likely be central to the organizing structure of increasingly convergent and integrating solutions.

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